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What is tall timber? Towards the formal classification of timber as a material of tall building design.

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ABSTRACT: The emergence of taller buildings using engineered timber as a structural material raises important questions about the language that is used to describe tall buildings. In the absence of formal definitions it is difficult to make meaningful comparisons between buildings using different materials, structural systems and building forms. Claims to the title of 'tallest timber building' are frequently made and may be subject to dispute. This paper discusses the role of the *CTBUH Criteria for Defining and Measuring Tall Buildings* in the classification of tall buildings and the challenges to the existing criteria raised by the emergence of engineered timber as a contemporary structural material. The paper highlights the authors' proposal for updating the existing terminology to accommodate the use of timber in the design of tall buildings and details the progress that has been made in moving towards a revision of the *CTBUH Criteria* to include timber. This progress is significant as it represents a critical step forward in bringing timber engineering into the mainstream discourse of tall building construction and places timber on a level playing field with steel and concrete.

KEYWORDS: Tall timber, height, structural material, definitions, terminology, criteria

1 INTRODUCTION

What is the world's tallest timber building? At present, this question has no clear answer – not least because there is no generally agreed formal definition of what constitutes a tall timber building. The absence of clearly understood terminology and criteria means that it is difficult for even a neutral observer to draw meaningful comparisons between buildings using different materials, structural systems and construction forms.

The need for clarity is becoming increasingly urgent in light of the rapid progress in the development of timber as a material for the construction of taller buildings. Such buildings have recently reached heights of 14 and 17 storeys in Bergen and Vancouver. Projects currently under construction are reportedly set to reach 18 and 24 storeys in Brumunddal and Vienna. Concept designs of 30 [1], 40 [2], 70 [3] and even 80 [4, 5, 6] storeys in cities as diverse as Vancouver, Chicago, Tokyo and London have also been proposed. This rapid development has led to inevitable claims and counterclaims to the title of 'tallest' without any generally agreed basis for comparison or common understanding of terminology.

This paper discusses the existing Council on Tall Buildings and Urban Habitat's (CTBUH) *Criteria for Defining and Measuring Tall Buildings* [7] – criteria that currently include only steel and concrete as structural materials. This paper assesses the challenges associated with the extension of these existing criteria to timber and highlights a proposal as to how this can be achieved. Finally, this paper details the progress that has been made towards the inclusion of timber as a revision to the existing criteria.

Figure 1: The 300m Oakwood tower concept for London. A vision for tall timber exists; but a formal definition does not. Image: PLP Architecture.

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2 EXISTING CRITERIA

The generally accepted guidance on tall building classification and terminology is the CTBUH's *Criteria for Defining and Measuring Tall Buildings* [7]. These criteria provide comprehensive guidance in relation to the determination of height and building materiality for the conventional materials of tall building construction – steel and concrete – but are silent on the use of timber and other new materials.

CTBUH Height Criteria
for Measuring & Defining Tall Buildings

The Council on Tall Buildings and Urban Habitat (CTBUH) developed the international standards for measuring and defining tall buildings, as outlined below, and is recognized as the arbiter for bestowing designations such as the "World's Tallest Building."

Tall, Supertall & Megatall Buildings

Tall Buildings
There is no absolute definition of what constitutes a "tall building;" the definition is subjective, considered against one or more of the following categories:

Height Relative to Context
A 14-story building may not be considered a tall building in a high-rise city such as Chicago or Hong Kong, but in a provincial European city or a suburb this may be distinctly taller than the urban norm.

vs.

Proportion
There are numerous buildings that are not particularly high, but are slender enough to give the appearance of a tall building. Conversely, there are numerous big/large-footprint buildings that are quite high, but their size/floor area rules them out of being classed as a tall building.

vs.

skyscrapercenter.com | ctbuh.org

Figure 2: *Currently silent on the subject of timber. The CTBUH Height Criteria for Measuring & Defining Tall Buildings available at www.ctbuh.org.*

Definitions of *tallness* are inevitably subjective and dependent to a large extent on context. In historical terms, a building that is taller than previous buildings of a particular material or type might well be said to be *tall*, in the sense of 'tall for a timber building'. Tallness in this sense is important to the engineering community, because engineering designers must draw on both experience and theoretical understanding. Buildings that exceed the height of precedents using similar materials or building systems thus present additional challenges, as the designer must do without recourse to precedent.

Another contextual consideration that has played an historical role in the technical definition of a building's tallness is that of fire. A building has often been considered 'tall' in the context of fire if its height is such that a fire in the building cannot be fought using ground-based equipment. This has constituted an historical 'basic height limit' in North America and elsewhere [8].

The CTBUH identifies three further qualities that can be used to define tallness:

- height relative to context;
- proportion;
- use of tall building technologies.

Height relative to context acknowledges that a building's surroundings play an important part in assessments of tallness. A 14-storey residential building sited in a suburban neighbourhood might be described as tall, while the same building situated in a high-rise cityscape might not be.

Proportion can be thought of as considering a building in the context of its own geometry and massing. A 14-storey building on a small footprint might be slender and thus appear tall, in a way that a 14-storey building covering an entire city block might not.

Tall building technologies are features such as advanced vertical transportation and enhanced lateral force-resisting and damping systems that are particular to the design of tall buildings. Enhanced lateral force-resisting and damping systems are in most cases closely related to the slenderness of a building. This aligns with the structural engineer's definition of "high-rise construction" [9] considering the relative significance of lateral forces due to wind and seismic actions, actual lateral sway, perceived lateral sway, and differential vertical movements due to thermal effects or axial shortening.

Defining tallness presents further challenges in the context of novel structural systems and new materials such as engineered timber where the lower stiffness and mass of timber could lead to wind or seismic actions governing design at considerably lower slenderness ratios, giving rise to the earlier use of enhanced lateral structural systems. This might be taken to suggest that buildings using timber should be considered "tall" at lesser heights than similarly sited and proportioned buildings using steel or concrete. However, recent research shows that the lateral performance of framed buildings using engineered timber, such as the Treet in Bergen, Norway, may not be dissimilar to that of a steel-framed equivalent [10, 11]. This suggests that it may be not be necessary to establish different criteria for tallness of timber buildings on the basis of material properties alone.

Definitions of height are objective and independent of context, provided that there is common understanding of where is being measured *from* and *to*. Variations in building form can make definitions of the top and bottom of a building somewhat arbitrary, but several broadly agreed measures are currently in use for the reporting and cataloguing of building height. The CTBUH recognizes three categories of tall building height:

- height to tip;
- height to architectural top;
- highest occupied floor.

These heights are measured from the finished floor level of the lowest, open-air pedestrian entrance leading to the main vertical transportation conduit. The *height to tip* measurement includes projections such as antennae that are not integral and may not be permanent features of the building. The *height to architectural top* or 'gross' height is the basis for the CTBUH list of World's Tallest Buildings and is measured to the permanent top of the building. This includes features such as spires but excludes antennae. Building classifications of super- and mega-tall are based on this gross height (CTBUH 2009).

Figure 3: *Tall timber? The 14-storey Treet building in Bergen, Norway. Image: Tor Orset.*

The difference between the height to architectural top and the *highest occupied floor* can undermine meaningful comparison between buildings. The measurement to the highest occupied floor or 'net' height is of greater practical interest for tall buildings in terms of their utility, and thus the measure of greatest interest for meaningful comparison. The *CTBUH Criteria* suggest a net height of approximately 14 stories or 50 meters as a starting point for consideration of a building as 'tall'. However, a building of lesser height could be considered based on how it uses tall building technologies.

Under the existing criteria, a building may be classified as one of four types, according to the materials used to construct the main vertical and lateral load resisting systems:

- Steel;
- Concrete;
- Composite;
- Mixed structure.

A *steel* or *concrete* building is defined as a building in which all of the main structural elements are constructed from steel or concrete. A *composite* building is defined as a building in which both steel and concrete elements are used to construct the main vertical and/or lateral load-resisting systems. This includes the very common structural typology of a steel-framed gravity load resisting structure built around a concrete core that provides the main lateral load resisting system. A *mixed-structure* building on the other hand is a building that uses distinct steel and concrete structural systems above or below each other. A steel/concrete building uses a steel structural over a concrete structural system; and a concrete/steel building uses a concrete structural system over a steel structural system.

A building with a steel frame but with a flooring system of concrete planks or slabs supported by steel beams is considered by the CTBUH as a *steel* building. As such the floor system is not considered to form part of the 'main' structural system, even though considerations such as diaphragm action or additional mass contributed by the flooring system may be integral to the design of the 'main' structure. This consideration recognises that, in addition to being internally consistent, a system of classification must reflect the realities of that which is classified. If the definition of a tall *steel* building required that all building components were steel; then the *steel* building category would be more or less empty, as virtually all steel framed buildings have concrete decks. Instead the *CTBUH Criteria* reflect what people mean when they talk about a steel building, which is that the primary structure – the main vertical and lateral load resisting systems – are constructed from steel.

These existing definitions provide a sound and widely agreed basis for the development of more comprehensive system of classification that includes timber and other new materials.

3 PROPOSAL

A proposal has been put forward by the authors [10, 11] for defining tall timber buildings with respect to the use of materials in the primary vertical and lateral load resisting structural systems. The format and language of this proposal is closely aligned with that of the existing CTBUH *Criteria for Defining and Measuring Tall Buildings* in order to ensure compatibility with existing terminology and, ultimately, to facilitate adoption by the CTBUH *Height and Data Committee*.

The proposal would rationalise the existing classifications from four to three:

- Single material;
- Composite;
- Mixed.

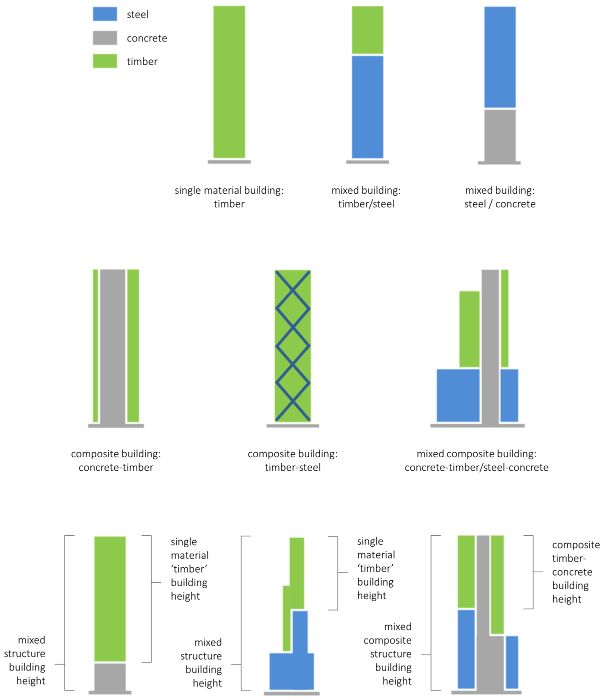

Figure 4: *Schematic classification system forming part of the proposal to CTBUH* [13]

A *single-material* tall building, whether steel, concrete, timber or some other material, is a building where the main structural elements are constructed from a single material. This leaves the definition of existing steel and concrete buildings unchanged, but brings them under the heading of a broader single-material category that would also include timber and any future materials of tall building construction such as fibre reinforced polymers or bamboo. In this way, conventional materials of tall building design are not placed in a privileged position over other potential structural materials.

As is currently the case, the materiality of any secondary flooring structure would not be considered as part of the "primary" structural material classification. This is compatible with the current guidance for the definition of a tall steel building with a concrete floor slab supported on steel beams.

The definitions of *composite* and *mixed structure* buildings would remain largely unchanged, except that reference to steel and concrete might be replaced with a reference to a wider range of materials. It might also be informative for a composite building to be designated by the constituent structural materials, hyphenated, in order of prevalence by mass in the building structure. Thus, a composite building with an extensive concrete core and limited timber framing would be designated as a *concrete-timber composite* building, while a mostly timber building whose lateral stability relies on continuous steel ties would be designated as a *timber-steel composite*.

4 CHALLENGES

Contemporary timber construction for taller buildings is not standardised, meaning that generalised classification and definition is particularly challenging. Timber is often used in combination with other materials such as steel and concrete, and this must be accommodated in any classification system. Similarly, it is common for the first one or two storeys of an otherwise timber building to be constructed from concrete and this too must be accommodated.

The design of any system of classifying real things involves a difficult balancing act between simplicity and exactness. Too simple and the system cannot distinguish between important differences in the things classified; too exact and the system becomes unwieldy and fails to capture important similarities. In particular, there can be a temptation to focus on outliers, on the 'hard cases' that seem resistant to simple taxonomy. The approach adopted here is that, in general, "hard cases make bad law" [12] and that these cases should be addressed in reference to the general principles set out above rather than resorting to ever more complex systems of classification. Some examples of hard cases are set out below, but first it is helpful to address some common features of buildings using timber that present challenges:

- Concrete lower storeys;
- Connections.

It is often the case that the lower one or two storeys of otherwise timber buildings are constructed from another material – usually concrete. This occurs for a range of reasons including robustness, preventing ground level moisture ingress, preventing ground level insect attack, retail functions at street level, etc. An analogous challenge to the classification of mixed-buildings with respect to use has already been addressed by the CTBUH. For the purposes of classifying building function, the CTBUH considers a building for which a single function makes up 85% or more of the total occupied height as a *single function* building. In the same manner it seems reasonable to classify a building for which a single material makes up 85% or more of the building height as a *single material* building.

Traditional methods for forming carpentered timber connections without the introduction of other materials are well-established in many countries. However, such connections are not generally used in modern buildings, where localized steel connections using plate-and-dowel, nailed bracket or self-tapping screw systems are the contemporary norm [9]. For this reason, non-timber materials used to form connections between timber elements are not considered in the classification scheme presented. This is comparable with the use of steel connections in a tall building with a precast concrete frame, or with reinforcing bars crossing a cold joint in a tall building with a monolithic concrete frame, which in both cases would be regarded as *concrete* rather than

The 14-storey glued-laminated mega-truss Treet building, incorporates 200 millimetre concrete topping slabs at the transfer stories in order to provide additional mass to the building to mitigate wind-induced lateral excitation. The 18 storey Mjøstårnet building incorporates concrete decking to the upper storeys for similar reasons. While this supplementary mass and the diaphragmatic stiffness of these slabs is in both cases considered in the structural design – as would be expected in a steel building with concrete decking on steel beams – the concrete does not in the authors' view provide a primary load path. This building would therefore be classified as a single-material timber building.

Figure 5: *Large steel plate and dowel connections of the Mjøstårnet building. Image: Jens Haugen/Anti.*

In contrast, existing European buildings such as Sweden's Limnologen in Växjö and Strandparken in Stockholm use systems of timber shear walls in conjunction with continuous steel ties. These ties thus form the primary tension force path of the lateral load resisting systems, meaning that these are timber-steel composite or hybrid load resisting systems. The Limnologen and Strandparken buildings are therefore considered to be timber-steel composite buildings under this classification scheme.

The US project Framework in Portland potentially provides an even harder case in the sense that it also uses a system of steel ties in conjunction with timber shear walls, but in order to resist the exceptional loads associated with a seismic event. If it is the case that for normal design loadings the steel tying system is not required as a load path, then it would seem appropriate to classify Framework as a single material timber building. If it is the case that the steel tying system is a necessary part of the main lateral load resisting system under normal design loadings then it would seem appropriate to classify Framework as a *timber-steel composite* building.

5 PROGRESS

Following publication of the initial proposal as a Forum discussion in the *ASCE Journal of Structural Engineering* [12], the *CTBUH Journal* invited the authors to submit a paper [13] informing the tall building proposal for consideration by the *CTBUH Height and Data Committee*. This proposal was also the subject of discussion at a *Tall Timber Workshop* preceding the *2017 CTBUH Conference* in Sydney organised by the CTBUH *Tall Timber* working group co-chaired by the first author and Carsten Hein, ARUP. The proposal has also been submitted to the Chair of the *Height and Data Committee* for consideration as an amendment to the formal *CTBUH Criteria* and the first Author has now been invited to attend a meeting of the *CTBUH Height and Data Committee* in October 2018 to discuss the proposal further.

CTBUH Special Report

Rethinking CTBUH Height Criteria In the Context of Tall Timber

Abstract

Recent developments in the design and construction of progressively taller buildings using engineered timber as a structural material raise important questions about the language that is used to describe tall buildings. This paper discusses the role of the CTBUH Height Criteria in classifying tall buildings and the challenges raised by the emergence of engineered timber as a contemporary structural material alongside steel and concrete. The paper concludes by presenting a proposal for updating the existing terminology to accommodate the use of timber and other new materials in the design of tall buildings. This paper will be used as a basis for discussion at the ***CTBUH Workshop on Tall Timber****, held in conjunction with the 2017 Conference, with a view towards the future revision of the CTBUH Criteria to include timber.*

Keywords: Height Definitions, Building Criteria, Timber, Materials

Introduction

Between 1885 and 1913, the development of steel-framed structural systems permitted the heights of skyscrapers to leap from the 10-story Home Insurance Building in Chicago, to the 60-story Woolworth Building in New York. Only 18 years later, the Empire State Building was completed at a height of 102 stories. Between 2008 and 2016, the height of modern buildings using engineered timber increased from the nine-story Stadthaus building in London to the 17-story TallWood at Brock Commons building in Vancouver (see Figures 1 and 2) (CTBUH 2017). Designs have also been presented for timber skyscrapers at heights up to 80 stories, including the River Beech Tower, Chicago and Oakwood Tower, London (see Figures 3 and 4) (Green & Karsh 2012, SOM 2013, Foster & Ramage 2016). Although it is impossible to know what heights tall buildings using engineered timber might ultimately reach, the historical precedent and the potential identified in recent design proposals suggest that genuinely tall timber buildings are likely to become a reality in the very near future.

The opportunities for better, more sustainable tall buildings afforded by new materials, new construction technologies and new architectural forms bring with them a range of

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Figure 6: *A proposal to update the CTBUH Criteria for Defining and Measuring Tall Buildings [13].*

6 CONCLUSIONS

This proposal and the possible revision of the *CTBUH Criteria* to include timber is significant because it represents a critical step forward in bringing timber engineering into the mainstream discourse of tall building construction. This will provide a more level playing field for timber, placing it on a more equal footing with steel and concrete as recognised materials of tall building construction. This will also allow the commercial drive to construct the tallest building of a particular type to play a positive role in the development of timber buildings, whilst ensuring that proper recognition is given to genuine progress and innovation in timber engineering and technology.

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